SURVIVAL OF COLIFORM ORGANISMS IN RIVER GANGA WATER NEAR KANPUR AND APPLICABILITY OF WATER QUALITY INDICES

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of

MASTER OF TECHNOLOGY

By

KASHI PRASAD

to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

JANUARY, 1977

CERTIFICATE

Certified that the work presented in this thesis entitled "Survival of Coliform Organisms in River Ganga Water Near Kanpur and Applicability of Water Quality Indices" by Shri Kashi Prasad has been carried out under my supervision and it has not been submitted elsewhere for a degree.

Malay Chaudhuri
Assistant Professor
Environmental Engineering Division
Department of Civil Engineering
Indian Institute of Technology,
Kanpur

December, 1976

ACKNOWLEDGEMENTS

I wish to record my great indebtedness to Dr. Malay Chaudhuri for his valuable guidance, stimulating discussions and constant encouragement throughout the course of this investigation and thesis preparation.

I owe a special debt of gratitude to Dr. G.D. Agrawal, Dr. A.V.S. Prabhakara Rao, Dr. S.D. Bokil, Dr. C. Venkobachar, and Dr.(Mrs.) Leela Iyengar for their interest during the progress of the study.

For physical assistance and moral support, fellow students and staff of the Environmental Engineering Laboratory, I.I.T., Kanpur are gratefully acknowledged.

SURVIVAL OF COLIFORM ORGANISMS IN RIVER GANGA WATER NEAR KANPUR AND APPLICABILITY OF WATER QUALITY INDICES

KASHI PRASAD

Environmental Engineering Division
Department of Civil Engineering
Indian Institute of Technology
KANPUR-208016

ABSTRACT

The first objective of the investigation was to study the survival of coliform organisms in river Ganga water and the factor(s) or principle(s) associated with coliform die-off. The second phase of the investigation was directed towards an assessment of the two recently developed water quality indices in terms of their applicability.

The results of the present study indicated that the factor(s) or principle(s) responsible for somewhat rapid die-off in Ganga water was suspended solids associated, heat labile and may be masked to some extent when high concentration of organic matter was present. The significance of this phase of the study in terms of public health was also discussed. Regarding the second phase of the study, the results demonstrated the usefulness of the two recently developed water

quality indices, viz., the NSF and the Walski-Parker models in predicting the quality of a natural body water. The Walski-Parker model was found to be more useful in predicting the water quality index for health-related uses whereas for non health-related activities, the two NSF models appeared suitable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The fundamental importance of water for life on the earth needs little justification. Indeed, modern industrial developments would scarcely be possible without an adequate supply of water in sufficient quantity and of the right degree of purity. Rivers and lakes, being formed from water which has percolated through the surface soil will contain dissolved salts, traces of organic matter, suspended matter, and dissolved gases. The activity of man, however, may lead to marked alterations in the natural composition of river water. The pollution of many of our rivers looms as a problem and represents a wasteful misuse of water, for in view of the rising consumption of water and of the diminishing amounts available from underground sources owing to demand exceeding supply, more use and reuse will undoubtedly have to be made of rivers in the future- even polluted reaches of rivers- as sources of supply for drinking and other purposes. In view of this use and reuse, the waste assimilative capacity of a river and the river water quality assume significance. The coliform index has long been the accepted standard for bacteriological quality of water and has always been included as one of the most important parameters in studies

designed to determine water quality of a river at a single point or at isolated points. However, stream studies are also designed to determin changing water quality throughout a reach as the water travels downstream and these involve a series of stations from which samples are collected and subjected to various physical, chemical, and biological analyses that reflect changes in constituents that result from natural purification and those that reveal effects of constituents of wastes discharged in the reach.

The present investigation was undertaken to study the survival of coliform organisms in Ganga water and the factor(s) or principle(s) associated with coliform die-off. The second phase of the study was directed towards assessing the applicability of two recently developed water quality indices using data collected during a survey of the Ganga River.

II LITERATURE REVIEW

A. River Pollution

From the scientific standpoint, it is perhaps easier to regard pollution as the actual impurity introduced into the stream rather than the act of introducing such impurity, and to define pollution as "anything causing or inducing objectionable conditions in any water course and affecting adversely any use or uses to which the water thereof may be put" (Klein, 1962).

Pollution of rivers may take place as a result of the discharge of raw or partially treated wastewater, or because of natural causes which may consist of runoff from land carrying silt, vegetable matter, manure, etc. washed into the river during storm. A classification of the kinds of pollution found in wastewater is given in Table 1.(Klein, 1962). The kinds of pollution commonly found in streams as a result of natural causes include organic minerals, suspended matter, turbidity, colour, odour, acidity and alkalinity.

Agricultural drainage includes important pesticides

and herbicides which are arsenic and copper compounds and such naturally occuring organic materials as pyrethrum, rotenone and nicotine. However, several synthetic organic compounds have been developed and older chemicals are being replaced. These are now extensively used for agricultural application. Unfortunately, some of these compounds are extremely toxic to birds, mammals and fish, and their spread and uncontrolled use as pesticides and weed killers can cause pollution of streams and fish mortality (Ingram and Tarzwell, 1955).

Table 1. Types of Pollution in Wastewater

Chemical	Physical	Physiological	Biological
Organic (carbon compounds)	Colour	Taste	Bacteria (pathogenic)
	Turbidity	Odour	
Inorganic (mineral compounds)	Temperature		Viruses
	Suspended solids		Animals
			Plants
	Foam		
	Radioactivity		

A peculiar form of river pollution arises from water associated with coal mining, including water pumped from abandoned mines. This mine drainage is usually low in organic matter but contains considerable amounts of ferrous and ferric salts, sulfates of aluminium, calcium and magnesium, and often sulfuric acid. The presence of sulfer and iron oxidising bacteria in acid mine water lends additional support of these views (Colmer and Hinkle, 1947)

B. Coliform Group as Index of Bacteriological Pollution

Biological contamination of water is defined as the introduction into, or the release or development in, water of potentially pathogenic organisms that renders the use of the water hazardous and therefore unfit for human consumption or domestic use (Ormerod and Kristensen, 1976). A list of pathogenic or parasitic agents that may be transmitted by water is shown in Table 2.

Pathogenic organisms occur in wide variety, imposes a severe restriction on their direct, and more particularly their quantitatively direct determination in routine analysis. As a result we are forced to resort to indirect qualitative evidence of the presence of biological contaminants. Indicator

Table 2, Pathogenic or Parasitic Agents Transmitted by Water

VIRA	BACTERIA		CYNOBACTERIA
Viruses ofinfectious hepatitis	Aeromonas	Salmonella typhi	Microcystis spp., Nodularia spumigena, Anabaena flos-aquae, Aphanizomenon flos-aquae
Enteroviruses	Bacillus anthracis	Salmonella paratyphi	
Adenoviruses	Clostridium botulinum	Salmonella spp.	
Reoviruses	Clostridium perfringns	Sigella spp.	
		Staphylococcus spp.	
FUNGI	Coliform bacteria with R-factor	Streptococci	PROTOZOA
Candida albicans	Enteropathogenic Escherichia coli	Haemotytic Lancefield group A and C	Balantidium coli
	Francisella tularensis	Streptococci Lancefield gr.B.	Entamoeba hystolytica
HELMINTHS			Giaradia lamblia
	Klebsiella spp.	Treponema spp.	Neagleria and Hartmanella
Nematode worms	Leptospira icterohaemorrhagiae	Vibrio alginolyticus	
Hook worm		Vibrio cholerae	
Guinea worm	Listeria spp.	Vibrio cholerae Nag	
Flat worm (tape worms, trematode)	Mycobacterium tuberculosis	Vibrio parahaemolyticus	
	Pseudomonas aeruginosa	Yersinia enterocolitica.	

organisms provide the substitute. As their name implies their determination points to pollution and to the possible presence of contaminating organisms. Biological indicator of contamination or pollution must satisfy the following criteria (Fair, Geyer and Okun, 1968):

(a) It must be a reliable measure of the potential presence of specific contaminating organisms both in natural and in the water that have been subjected to treatment. To meet this requirement, the indicator organisms must react to the natural aquatic environment and to treatment processes, including disinfection in the same way relatively as do contaminating organisms. When such an indicator organism is used experimentally it becomes simulant.

(b) It must be present in numbers that are relatively much larger than those of contaminating organisms whose potential presence it is to indicate. Otherwise, the presence of the contaminating organisms itself would serve a more directly useful purpose.

(c) It must be readily identified by relatively simple analytical procedures. Few sanitary works can afford the service of biological specialists.

(d) It must lend itself to numerical evaluation as well as qualitative identification since the knowledge of the degree of contamination is an essential interest and responsibility of the engineer.

Bacteriologists have evolved simple and rapid tests for the detection of intestinal organisms which are easier to isolate and identify, e.g., coliform bacteria, fecal streptococci and anaerobic, sulfite reducing sporeformer. The presence of such fecal bacteria in a water sample indicates that pathogen could be present (Ormerod and Kristensen, 1976).

The organisms most commonly used as indicators of fecal pollution are the coliform group as a whole, and particularly Escherichia coli. The "coliform organisms" usually refers to gram-negative, oxidase negative, non-sporing rods capable of growing aerobically on an agar medium containing lactose with production of acid and aldehyde or non-sporing rods able to ferment lactose with production of both acid and gas within 48 hours at 35-37C°. The group of coliform bacteria fermenting lactose at 30°C is fairly widespread in nature and is not considered to be of any particular epidemiological importance in the examination

of waters. *Escherichia coli* is a coliform organism, as defined above, which is capable of fermenting lactose in broth with the production of acid and gas at both 35-37°C and 44°C in less than 48 hours, which produces indole in peptone water containing tryptophan; which is incapable of producing acetyle methyl carbinol; and which gives a positive result in the methyl red test (European Standards, 1970; and International Standards, 1971). *Escherichia coli* is undoubtedly of fecal origin, but as other coliform organism are wide-spread in nature, their presence in water has been much debated; however, all the members of the coliform group(as here defined) may be of fecal origin. Various studies have been made to develop methods more selective for the coliform bacteria of undoubtful fecal origin. Results obtained with these "fecal coliform" methods have shown that this group of bacteria is a better indicator of pollution by worm-blooded animals than the traditional total coliform procedure when applied to stream pollution investigations, wastewater treatment systems, and bathing water quality (Ormerod and Kristensen, 1976).

Numerous workers have justified the use of fecal coliform bacteria as an indicator of fecal pollution and

hence a possible public health hazard, Gallagher and Spino, 1968; and Geldreich, 1966 and 1970). It has also been shown that salmonella species have similar survival properties in natural waters (Geldreich, 1970 and Rudolfs and Ragotzkie, 1950). However, adequacy of the coliform group as indicator of virus pollution has been severely questioned and it has been shown that fecal coliform and salmonella species have the most rapid decline rate in natural water of all of the microorganisms of public health significance (Geldreich, 1966; Joyce and Weiser, 1967; and Van Donsel and Geldreich, 1971).

C. Density of Coliform Organisms in Natural Waters and Their Survival

The density and survival of coliform bacteria in rivers and streams have been reviewed by Berg et al. (1966). Large quantities of coliform and other bacteria enter rivers and streams with municipal wastewaters. The number of coliform organisms in human feces averages 1.95 billion per day per capita. Raw municipal wastewater from large cities contains a most probable number (MPN) of 15 to 30 million coliforms per 100 ml in summer and 5 to 10 million in winter. The number of coliform organisms may increase as the wastewater enters a stream, and a maximum density may

occur after 10 to 15 hours. Coliform counts at maximum density may be 4 to 8 times the number discharged from the outfall. ~~Studying~~ A number of factors effect the survival of bacteria in river and streams, which are discussed below:

(a) Temperature

Temperature influences bacterial survival in natural water (Frost and Streeter, 1924 and Hoskins, 1926). Bacterial population of the Ohio River decreased considerably during the warmer months; however, the counts were stable during the cold months. Hanes et al. (1966) observed in their laboratory studies that the length of the log phase of the coliform group increased with a decrease in temperature. The average death rate for the coliform group was found to be lower than that for the enterococcus group at all temperatures studied (10 to 30°C). There is a general feeling that in any given environment at ordinary temperatures it is impossible to predict the effect of temperature changes on the survival of enteric organisms other than to say that the tendency for increased survival is greater at lower temperature (Greenberg and Arnold, 1956).

(b) Animal Predators and Antibiotics

To explain the initial increase in bacterial numbers in a stream, Hoskins and Butterfield (1933) suggested that normally protozoa and other agents keep the bacterial density of water below a limiting level and that on dilution, the bacterial concentration needed by the protozoa is no longer available. The bacteria, therefore, multiply (if other conditions are favourable) at a rate more rapid than the protozoa. There is a marked increase in the bacterial density before a biological balance is restored. Purdy and Butterfield (1918) demonstrated that protozoa increase in numbers as the bacterial numbers in polluted water decrease. Some of the bacterial increase may reflect disintegration of aggregates and clumps (Streeter, 1931). While reviewing the available data on the survival of enteric organisms in sea-water, Greenberg and Arnold (1950) concluded that the simple most important factor in reducing the number of enteric bacteria in seawater is a biological one and most likely is the result of the production of antibiotic substances by marine bacteria.

Ketchum *et al*. (1952) completed a study of a tidal estuary with a mathematical analysis of the factors

contributing to the decrease in coliform counts and showed that bactericidal action was considerably more significant than either dilution or predation. Unevaluated factors were from 3 to 7 times as effective as dilution but were not as effective as bactericidal action in reducing counts.

(c) Rainfall

Rainfall results in large increases in number of bacteria in streams. Palmer (1950) found a coliform MPN of over 4 million per 100 ml of stormwater overflow from combined sewer systems. Berg et al. (1966) demonstrated that below Kansas City, high coliform counts occurred in the Missouri River from the second to the fourth day after rain at Kansas City.

(d) Nutrients

Food supply appears to be a responsible factor in bacterial die off in streams (Kittrell and Furfari, 1963). Hendricks and Morrison (1967) have demonstrated that municipal wastewater treatment plant effluent can add sufficient organic and inorganic nutrients to stimulate the growth of enteric bacteria to levels higher than that of uncontaminated water. They also have observed that the

aquatic environment associated with a clear, uncontaminated mountain stream not only can maintain populations of enteric bacteria but also can supply sufficient nutrient to initiate multiplication and de novo protein synthesis. Streams that receives industrial wastes containing sugar have high coliform counts. The nutrient factor may be related to the total microflora in the stream also, for as the bacteria multiply their predators also multiply (Berg et al. 1966). In the event that there is sufficient organic matter present to support growth, a competition between enteric organisms and saprophytes would follow; generally, the enteric organisms would be unequal to competition(Greenberg and Arnold 1956).

(e) Sorption and Sedimentation

Sorption of bacteria to particulate matter followed by their sedimentation tends to remove the organisms from suspension and concentrate them in bottom deposits where the may continue an active existence(Greenberg And Arnold,.1956). The role played by sorption and sedimentation in reducing the bacterial number will be affected by the nature of bottom deposits, the rate of desorption,and the rate of water movement.

(f) pH

The pH of most of natural surface waters is 6.7 to 8.3. Too much acidity or alkalinity causes a rapid die-off of many microorganisms. In buffer at pH 11 Salmonella typhosa dies off rapidly, but Escherichia coli may increase in number at this pH; however, at pH 12, Escherichia Coli, too, dies off rapidly (Berg *et al.* 1966).

(g) Sunlight

The disinfecting property of ultraviolet light (UV) is well known. However, UV light does not penetrate water well. In moderately turbid water, the sun's rays are not strongly bactericidal (Jordan, 1900).

(h) Stream Characteristics

Coliforms disappear more rapidly in a small turbulent stream than in a large river (Kittrell & Furfari, 1963). The rapid die-off in small turbulent stream has been attributed to the intermittent riffle areas where attached biological forms concentrate. Large streams usually do not have these riffle areas.

(i) Other Factors

There are other factors not clearly defined which reduce the bacterial population in stream (Berg et al, 1966). Bacteriophages destroy bacteria, chemical pollutants may be toxic to bacteria and the lack of special nutrients such as vitamins could limit bacterial multiplication. Dissolved oxygen is also a factor that determines the kind of microflora in a stream.

The bacterial die-off in streams appears to have as does the BOD curve, atleast two distinct rates of decrease (Kittrell, 1969). The coliform bacteria exhibit an initial extremely rapid decrease that results in 90 to 95 percent reduction of initial densities in two days in summer and 80 to 90 percent reduction in two days in winter. The reduction in five days may be 99 percent or more in summer and 95 percent in winter. Frost and Streeter (1924), and Kittrell (1969) suggested that the following formula adequately fitted the bacterial die-off curve:

$$y = a\ (10^{-bx}) + c\ (10^{-dx})$$

where y = portion of maximum bacterial density remaining after time x,

a = portion of initial bacteria decreasing at rate defined by coefficient b, and

c = portion of initial bacteria decreasing at rate defined by coefficient, d.

Numerical values for the factors in the formula for bacterial die-off curves in the Ohio River were given, but they were not proposed for general application to other streams. Hoskins (1926) summerised data from the Ohio and Illinois Rivers and presented two series of idealised summer and winter die-off curves, with rates proportional to initial densities. He suggested that these rates might be applicable generally to other streams. Kittrell and Furfari (1963) reviewed the earlier data and reports on coliform bacteria, especially those of Frost, Streeter, and Hoskins, and confirmed much of the material with data from their stream study.

D. Water Quality Indices

The idea that "quality" is a dimension of water that requires measurementin precise numbers is of quite recent origin (McGauhey, 1968). A need to quantitate, or give numerical values to the dimension of water known as "quality" derives from almost every aspect of modern industrialised society. For the sake of man's health we require by law that his water supply be "pure, wholesome, and potable." In many instances, e.g., irrigation, industry, etc. water is one of the raw materials the quality of which must be precisely known and controlled. With these myriad activities going on simultaneously and intensively, each drawing upon a common water resource and returning its wastewater to the common pool, it is evident to even the most casual observer that water quality must be identifiable and capable of alteration in qualitative terms if the word is to have any meaning or be of any practical use. The identification of quality is not itself an easy task, even in the area of public health where efforts have been most persistent. Second dilemma lies in the definition of the word "quality". While the dictionary may suggest that quality implies some sort of positive attribute or virtue in water, the fact remains

that one water's virtue is another's vice. Thus, after all the impurities in water have been cataloged and qualified by the analyst, their significance can be interpreted in reference to quality only relative to the need or tolerances of each benefecial area to which the water is to be put.

In current practice, where multiple uses are required, as they will be in most situations, the guidlines to action will be the more stringent criterion. Criteria may be defined as "the scientific data evaluated to derive recommendations for characteristics of water for specific uses" and represent attempts to quantify water quality in terms of its physical, chemical, biological, and aesthetic characteristics (Water Quality Criteria, 1972). If adequate criteria for recommendations are available and the identification and monitoring procedures are sound, the fundamentals are available for the establishment of effective standards. However, at this step political, social, and economic factors enter into the decision making process to establish standards.

During the past decade water quality engineers became aware of the neccessity and usefulness of a water quality index (WQI) as a single numerical expression

reflecting the composit influences of the water quality parameters significant for a specific beneficial use. Horton (1965) defined a WQI based on entirely physical and chemical measurements and included eight parameters, i.e., sewage treatment, dissolved oxygen, pH, coliform density, specific conductance, carbon chloroform extract, alkalinity, and chloride. The weights and ratings were given on the basis of stream quality and personnel opinion.

Brown _et al_.(1970) of the National Sanitation Foundation (NSF), U.S.A. undertook the development of a WQI (a number varying between 0 and 100) incorporating many aspects of DELPHI (Dalkey, 1968), an opinion research technique developed by the Rand Corporation. Individual judgements of large panel of experts were integrated. Through controlled feedback, each panelist was given the oppertunity to compare his individual response with that of the group, and to change his response to more nearly conform with the group if he considered it desirable to do so. A panel of 142 persons were carefully selected and three successive questionnaires were mailed to respondents. The first two questionnaires helped to reduce the original thirtyfive selected parameters

to eleven for consideration. In the third questionnaire the respondents were asked to assign values for the variation in level of water quality produced by different levels of nine of the eleven individual parameters which included dissolved oxygen, fecal coliform density, nitrates, phosphates, 5 day BOD, equilibrium temperature(temperature known to occur without the influence of heated or cooled discharge) total solids and turbidity. This was accomplished by utilising a series of "Quality Curves" in which levels of water quality from 0 to 100 were indicated in ordinate, and various levels (strength) of the particular parameter were arranged along the abscissa.Average curves for each parameter were produced by combining the curves returned by different respondants (McClelland, 1974) . For the last two parameters, viz., pesticides and toxic elements, it was proposed that the WQI would be zero if the total content of detected pesticides exceeded 0.1 mg/l or if any toxic element exceeded its maximum permissible level permitted in the USPHS Drinking Water Standards (1962). From the data on parameter weightings supplied by the respondants final weights were derived for each parameter included in the proposed WQI:

$$WQI = \sum_{i=1}^{n} w_i \; q_i$$

where, WQI = the water quality index,

a number between 0 and 100 (theoretical);

q_1 = the quality of the ith parameter,

a number between 0 and 100 (read from the quality curves);

w_i = the unit weight of the ith parameter,

a number between 0 and 0.17; and

n = the number of parameters.

Despite the apparent responsiveness of the additive WQI to changes in water quality conditions analysis of data from field study suggested that it lacked sensitivity in adequately reflecting the effect of a single low value parameter on overall water quality. As a result, a multiplicative form of WQI was proposed (Brown <u>et al</u>., 1973):

$$WQI\ (M) = \prod_{i=1}^{n} q_i^{\,w_i}$$

where, WQI(M) = The multiplicative water quality index,

a number between 0 and 100;

q_i = the quality of the ith parameter,

a number between 0 and 100;

w_i = the unit weight of the ith parameter,

a number between 0 and 0.17; and

n = the number of parameters.

The above mentioned NSF water quality indices were applied successfully to selected sites in the Kansus River and it was observed that these were responsive to changes in water quality resulting from dischange of municipal and industrial waste-water effluents and agricultural runoff (McClelland, 1974).

Walski and Parker (1974) proposed a WQI based on a geometric mean of the sensitivity functions (transformed values) of selected water quality parameters:

$$WQI = \left[\prod_{i=1}^{n} (f_i(p_i)) \right]^{1/\sum_{i=1}^{n} a_i}$$

where, p_i = value of ith parameter;

$f_i(p_i)$= sensitivity function for ith parameter;

a_i = weight attached to ith parameter and

n = total number of parameters;

The selected parameters included temperature, nutrients , suspended solid, turbidity, coliform, dissolved oxygen, colour,pH, etc. The sensitivity functions employed possesed a range from zero to one with one representing ideal condition and zero representing completely unacceptable condition. Data available in the literature including those from Water Quality Criteria (McKee and Wolf, 1963) and USPHS Drinking Water Standards (1962)

were used for determining the sensitivity functions. A weight of one was attached to all the parameters except coliform density which was assigned a weight of two. The index was applied with limited success to some surface waters near Nashwille, Tennessee, U.S.A.

Harkins (1974) observed that the NSF water quality index was not really objective because a panel of 'experts' rated the water quality parameters to be used. It was felt that different panels would give different ratings, thus destroying comparability and objectivity. He proposed an objective water quality index using a technique developed by Kendall (1963) which is a distribution-free stastical procedure consisting of computing the standardised distance each observation lies from a well chosen control observation(optimum condition). The only hindrance in using this method is that the number generated in one evaluation can not be directly compared with those generated by a different run, the two sets of raw data must be combined and a new evaluation of the total data set made.

A water quality index, for the recreational users of urban waterways has been proposed recently by Frenkil (1975). The proposed index is in essence a

combination of the indices developed by Brown et al. (1970) and Walski and Parker, (1974). The application of the water quality index was also demonstrated through an interpretive example of the Allegheny River in the United States.

In reviewing the efforts made in the recent past in developing water quality indices it appears that additional research into developing additional ones, and refining the criteria used in their development is waranted. Also, additional applications of the available indices will presumably generate improvements of the available models.

E. The Ganga River Studies

The Ganga basin of India is the largest, comprising one-fourth of the total area of India and drains the great Indo-Gangetic plane, one of the most densely populated areas in the world. The Ganga River originates from Gangotri in the Himalayan mountains at the height of approximately 25,000 feet above see level, and after flowing for about 1500 miles through agricultural land falls into the Bay of Bengal near Calcutta. It recieves various forms of municipal and industrial wastewaters,

often untreated or partially treated, originating from a large number of industrial centres and metropolitan cities located on its bank. In the recent years, rapid population growth coupled with increased industrialisation and urbanisation has enhanced the pollution load of the river to a great extent.

It is rather surprising that inspite of the heavy pollution load of the Ganga River, no systematic survey of the river was undertaken in the past. Presumably, there were some analyses of the river water samples collected at scattered locations which were never reported in the literature. The first systematic survey of the physical, chemical, and biological quality of the river was undertaken by Saxena _et al_. (1966). The survey was carried out in the different seasons of the year 1964-65 near Kanpur using twelve different sampling stations. The survey revealed that the quality of the Ganga water was reasonably satisfactory at Bhairon Ghat Pumping Station which is upstream of the first wastewater outfall and serves as the city's water intake. The river water quality was found to deteriorate in the dredged channel after recieving the municipal and industrial wastewater discharge and improved near the Railway Bridge where the dredged

channel confluenced with the main stream of the river. The quality was found to deteriorate again in the Jajmau area where it gets gross pollution load from the tanneries and the city wastewater pumping station.

Khanna et al. (1971) conducted an investigation to test in a scientific manner the folklore regarding the unusual "keeping quality" of the Ganga River water even after long storage. Three most plausible reasons for rapid bacterial die-off, viz., the presence of ratioactive substances, bacteriophages, and transition metals possesing bactericidal properties were investigated. They studied the effect of storage at room temperature (30 $\pm$ 2 ^{o}C) on bacterial survival in the Ganga river water collected at Laxman Jhoola and compared that with bacterial survival in Jamuna River water collected at Tajewala (Jagadhari). Reduction in bacterial number in The Jamuna water was not complete even after fifteen days of storage, whereas a complete reduction was achieved in seven days in the Ganga water. During the same period of storage the bacterial number in Jamuna water reduced only 26 percent. Using the limited data collected, they ascribed the unique keeping quality of the Ganga River water to the presence of bacteriophages in the water and heavy metals in the river bed.

III SCOPE OF THE PRESENT STUDY

From a review of the literature it is apparent that the survival or die-off of coliform organisms in natural water systems has long been of concern to the environmental engineers engaged in river pollution studies. Several studies in this area were undertaken in many major rivers of the United States. Inspite of the folklore regarding the unusual "keeping quality" of the Ganga water, only one study (Khanna et al., 1971) in this area has been reported. It seems appropriate to further study the factor(s) or principle(s) responsible for coliform die-off in the Ganga water. Regarding water quality, only one systematic survey of the river Ganga was conducted which included a reach of the river near Kanpur. It is also felt that the recently developed models for water quality index need to be tested with regard to the Ganga River so as to be able to ascertain their applicability.

The first phase of the present study was devoted to investigate the survival or die-off of coliform organisms in Ganga water both in the laboratory and *in situ*. The objective of the second phase of the study

was to test the applicability of the two presently available water quality indices using water quality data collected during the present study as well as that available from a previous study (Saxena et al., 1966).

IV. MATERIALS AND METHODS

A. Coliform Bacteria

Coliform bacteria isolated from Ganga water was grown into stock cultures in nutrient agar slants and used throughout the study. It was identified as *Escherichia coli* by the following cultural characteristics : growth and gas production on Brilliant Green Lactose Bile (BGLB) broth and growth on Eosin Methylene Blue (EMB) agar in 24 $\pm$ 2 hour at 37 $\pm$ 0.5°C. Before using in survival studies, the *Escherichia coli* was grown in nutrient broth for 24 $\pm$ 2 hour at 37 $\pm$ 0.5°C and cells were harvested by centrifugation (3020 x g) for 10 minutes followed by washing twice with sterile 0.85 percent saline solution (physiological saline). The cells were then suspended in sterile physiological saline, enumerated using EMB agar pour plates at 37 $\pm$ 0.5°C for 24 $\pm$ 2 hour (Standard Methods, 1971) and diluted to the desired population density for use in survival studies.

B. Laboratory Studies on Coliform Survival

Water samples for this phase of the study were collected from the Ganga River at two different locations, viz., Bhairon Ghat and the Railway Bridge (Fig. 1). Bhairon

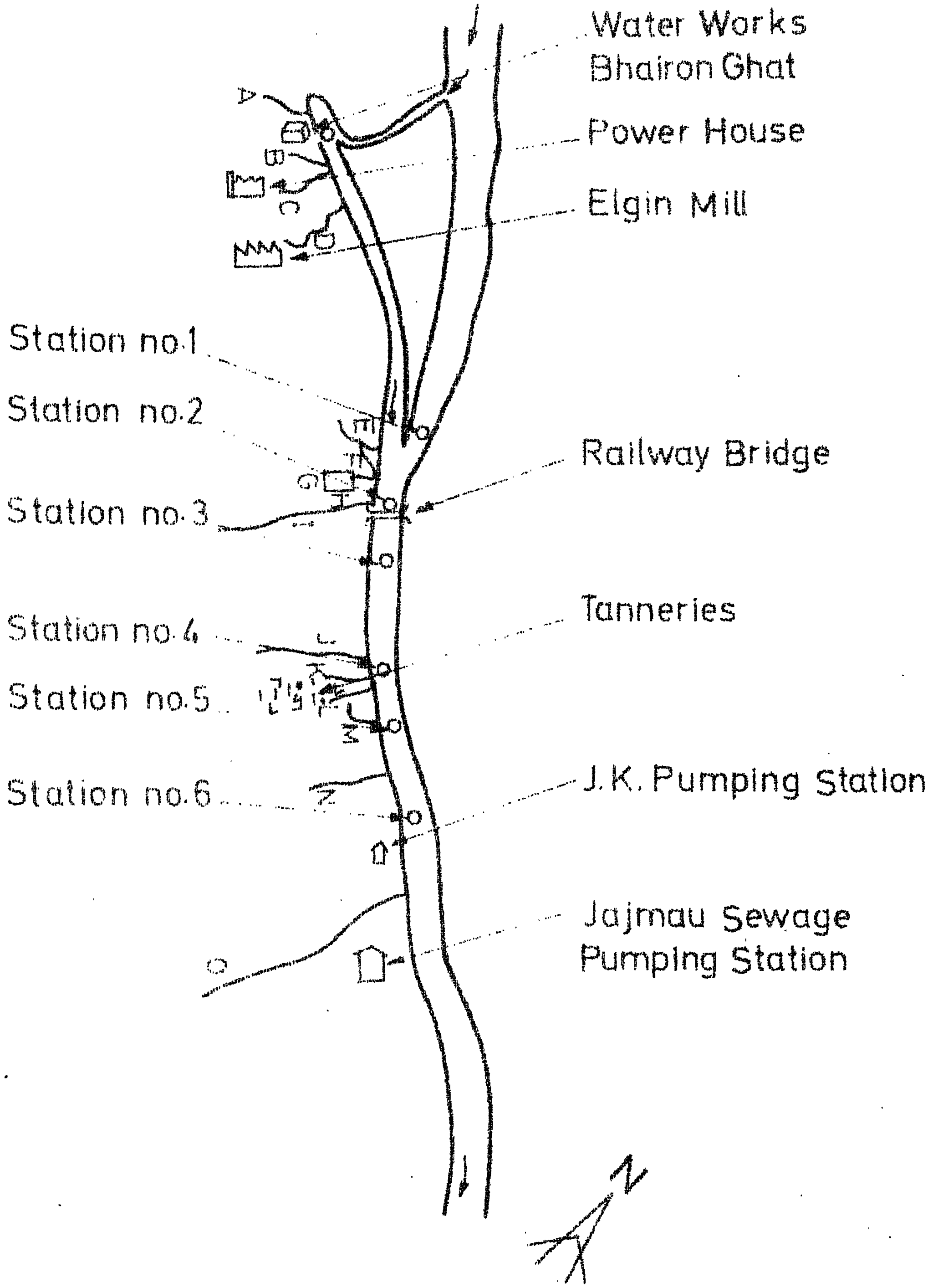

Fig.1 Ganga river near Kanpur showing the location of sampling stations

Ghat is situated on the upstream reach of the dredged channel and serves as the water supply intake for the Kanpur City. The downstream reach of the dredged channel receives wastewaters from several tanneries and textile mills as well as from a number of municipal wastewater outfalls. The Railway Bridge is located downstream of the point where the dredged channel joins the main river. It was thought that the Bhairon Ghat sample would represent a relatively unpolluted sample whereas the Railway Bridge sample would be more polluted. The water samples were characterised in terms of pH, chemical oxygen demand (COD), total dissolved solids (TDS), suspended solids, turbidity, and total coliform count using the procedures given in the Standard Methods(1971).

For use in the survival study, the samples were subjected to the following physical treatment : (i) filtration through 0.45μm membrane filter (Millipore Corporation, Bedford, Mass., U.S.A); (ii) autoclaving at 15 psi for 30 minutes; and (iii) autoclaving followed by membrane filtration. Screw-cap culture tubes (100 ml) in duplicate were used for the survival study. A set of eight culture tubes containing the untreated and treated water samples with an input <u>Escherichia coli</u> concentration of 3.2×10^9 per ml were kept immersed in a constant temperature water

bath at 37 $\pm$ 0.5°C. Survival pattern was followed by withdrawing one ml samples at selected time intervals and plating triplicate EMB agar pour plates as described before.

C. In Situ Studies on Coliform Survival

Dialysis tubings (36/32" size; Batch No. SB 68d) obtained from the Biochemical Unit, V.P. Chest Institute, University of Delhi were used for this study. Eight dialysis sacs prepared by tying both ends of a 15 cm long dialysis tubing and containing 6 x 10^7 per ml *Escherichia coli* suspended in 50 ml of physiological saline were placed in a wire mesh cage, transported to Bhairon Ghat, and immersed in the Ganga River 45 cm below the surface. Two sacs were transported daily to the Environmental Engineering Laboratory for bacterial enumeration using EMB agar pour plates as described before.

D. Effect of Suspended Solids on Coliform Survival

In order to study the effect of suspended solids and/or suspended solids associated materials on coliform survival, two 500 ml samples of Ganga water from Bhairon Ghat were autoclaved and filtered through membrane filters to obtain the suspended solids. One of the membranes containing the suspended solids was then placed in a 100 ml

Erlenmeyer flask containing 50 ml of physiological saline and thoroughly shaken for 24 hours in a rotary shaker. The content of the flasks was then filtered through a membrane filter to get the leachate. A set of three 100 ml Erlenmeyer flasks containing physiological saline, physiological saline and suspended solids and the leachate in physiological saline were then inoculated with an input Escherichia coli concentration of 5.5×10^8 per ml and kept immersed in a water bath at $37 \pm 0.5°C$. Survival pattern was followed by withdrawing and plating samples on EMB pour plates as described before.

E. Ganga River Survey and Application of the Water Quality Indices

A reach of the Ganga River, about 6 km long was selected for this phase of the study designed to investigate the applicability of the NSF and Walski - Parker water quality indices. This reach extends from a point in the main stream of the river just above the confluence of the dredged channel at Gola Ghat to the J.K. Pumping Station located about 1 km upstream of Jajmau and receives wastewaters from a number of tanneries and municipal wastewater outfalls. The dredged channel which meets the selected reach of the

river just downstream of the first sampling station receives wastewaters from tanneries, textile mills, municipal wastewater outfalls, and the Riverside Thermal Power Station, Samples were collected from the middle of the stream at a depth of 45 cm at six stations located on the selected reach of the river (Fig. 1) during May, 1976. The samples were analysed for pH, turbidity, 5 day biochemical oxygen demand (BOD_5), dissolved oxygen, total coliform, suspended solids, phosphate and nitrates which were the parameter selected for inclusion in the water quality indices. This stretch of the river was also included in an earlier water quality survey (Saxena _et al_., 1966).

While computing water quality indices using the NSF models, qualities (q_i) of the selected parameters were read from the NSF quality curves (Fig. 1A and 2A). For unit weights (w_i) of the selected parameters, the values used by McClelland (1974) were employed. For Walski-Parker water quality index computations, sensitivity functions for the selected parameters were read from the relationships used by Walski and Parker (1974) and shown in Table 1A except for biochemical oxygen demand (BOD_5) for which the following sensitivity function relationship was employed :

$$f\ (BOD_5) = \exp\ (-0.346\ BOD_5)$$

The recommended limit for BOD of raw water is 1.5 to 2.5 mg/l (McKee and Wolf, 1963) and it was felt that 2.0 mg/l should represent a value of 0.5 on the sensitivity function.

V. RESULTS AND DISCUSSION

A. Coliform Survival

Figure 2 is a plot of coliform survival in two Ganga water samples collected at Bhairon Ghat and Railway Bridge as well as the data obtained during the *in situ* study conducted at Bhairon Ghat using dialysis sacs. Data on coliform survival in the rivers of the United States have also been plotted for the purpose of comparison. It is apparent that the coliform die-off in the Ganga River at Bhairon Ghat is more rapid compared to that observed in the rivers of the United States. However, the coliform die-off in the water sample collected from Railway Bridge is slower compared to that observed with the Bhairon Ghat water sample. While comparing the percent reduction in bacterial numbers in stored water samples collected from the Ganga and Jamuna Rivers, Khanna *et al*.(1971) observed that in the Jamuna water sample reduction was not complete even after fifteen days of storage whereas a complete reduction was achieved in the Ganga water sample in only seven days. On the basis of the limited data on coliform survival, it is apparent that coliform die-off is more

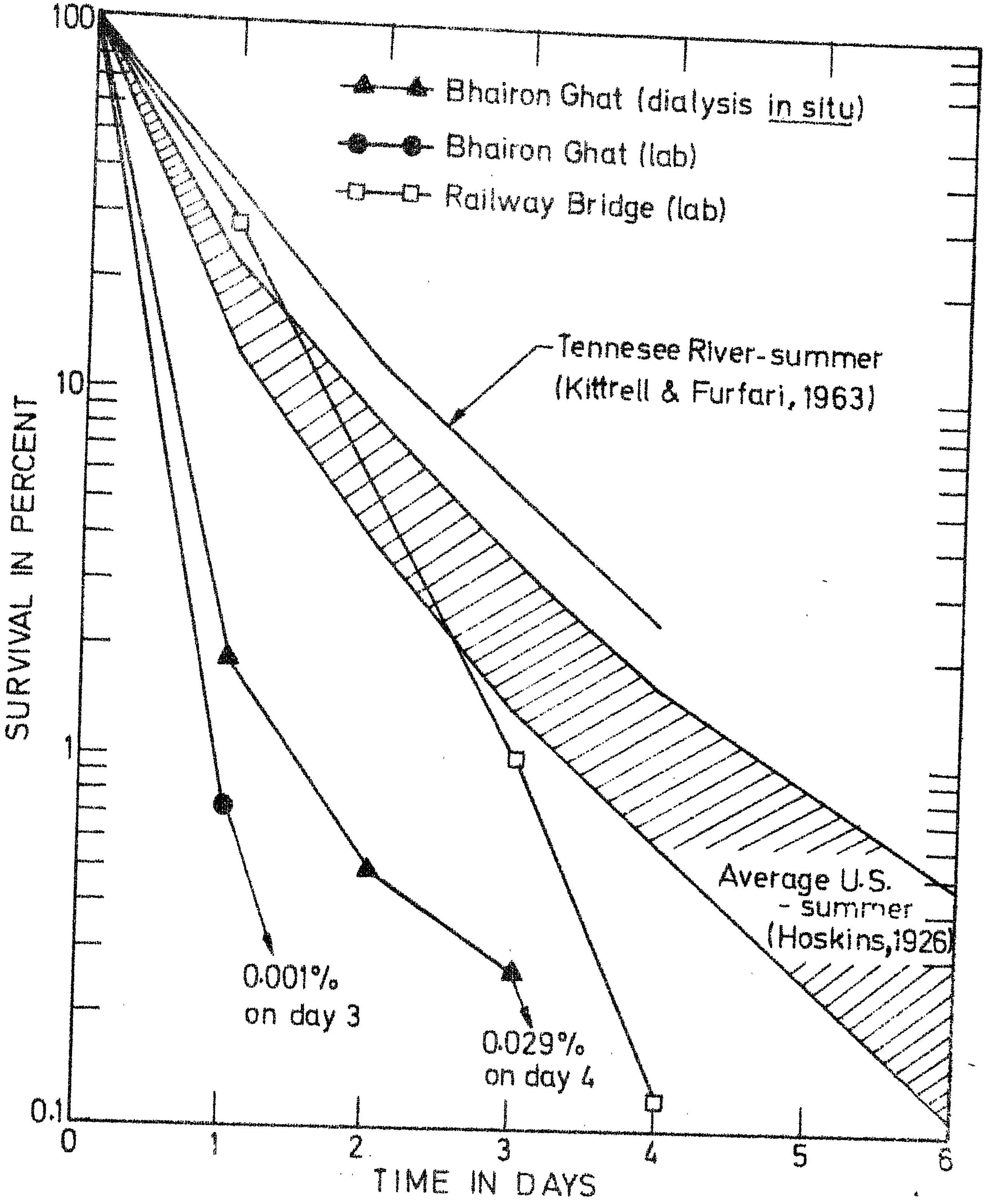

Fig.2 Coliform survival in Ganga water and major U.S. rivers

rapid in Ganga water compared to that observed in other rivers.

In order to probe into the factor (s) or principle (s) which may be responsible for rapid coliform die-off in Ganga water detailed laboratory studies on coliform survival were conducted using the Ganga water samples from Bhairon Ghat and Railway Bridge (Fig. 3 and 4). Decreased coliform die-off observed in the filtered Bhairon Ghat water sample (Fig. 3) indicates that one of the factors responsible for rapid die-off is probably suspended solids associated. Further decrease in die-off observed in the autoclaved water sample designates a heat labile factor or principle. It is also quite probable that chemical compounds (suspended and dissolved) present, but unavailable as nutrients to coliform organisms, were decomposed during autoclaving and produced products "which enabled the coliform organisms to maintain themselves more efficiently" as pointed out by Greenberg and Arnold (1956). Coliform die-off in the filtered and autoclaved water sample falls in between that observed in the samples which were filtered and autoclaved separately. This is presumably due to less availability of food and nutrients compared to the autoclaved sample because

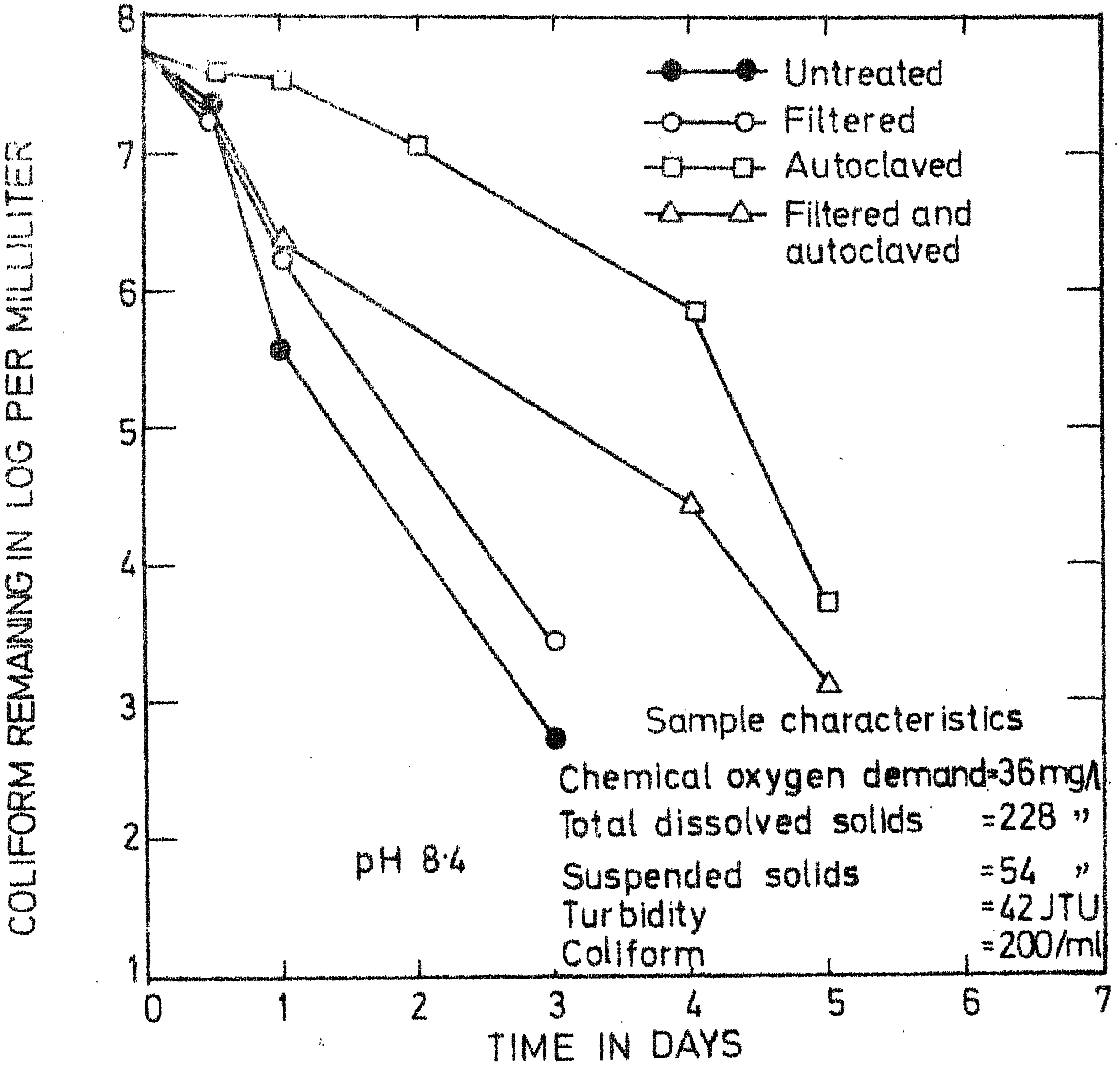

Fig. 3 Coliform survival in Bhairon Ghat water sample

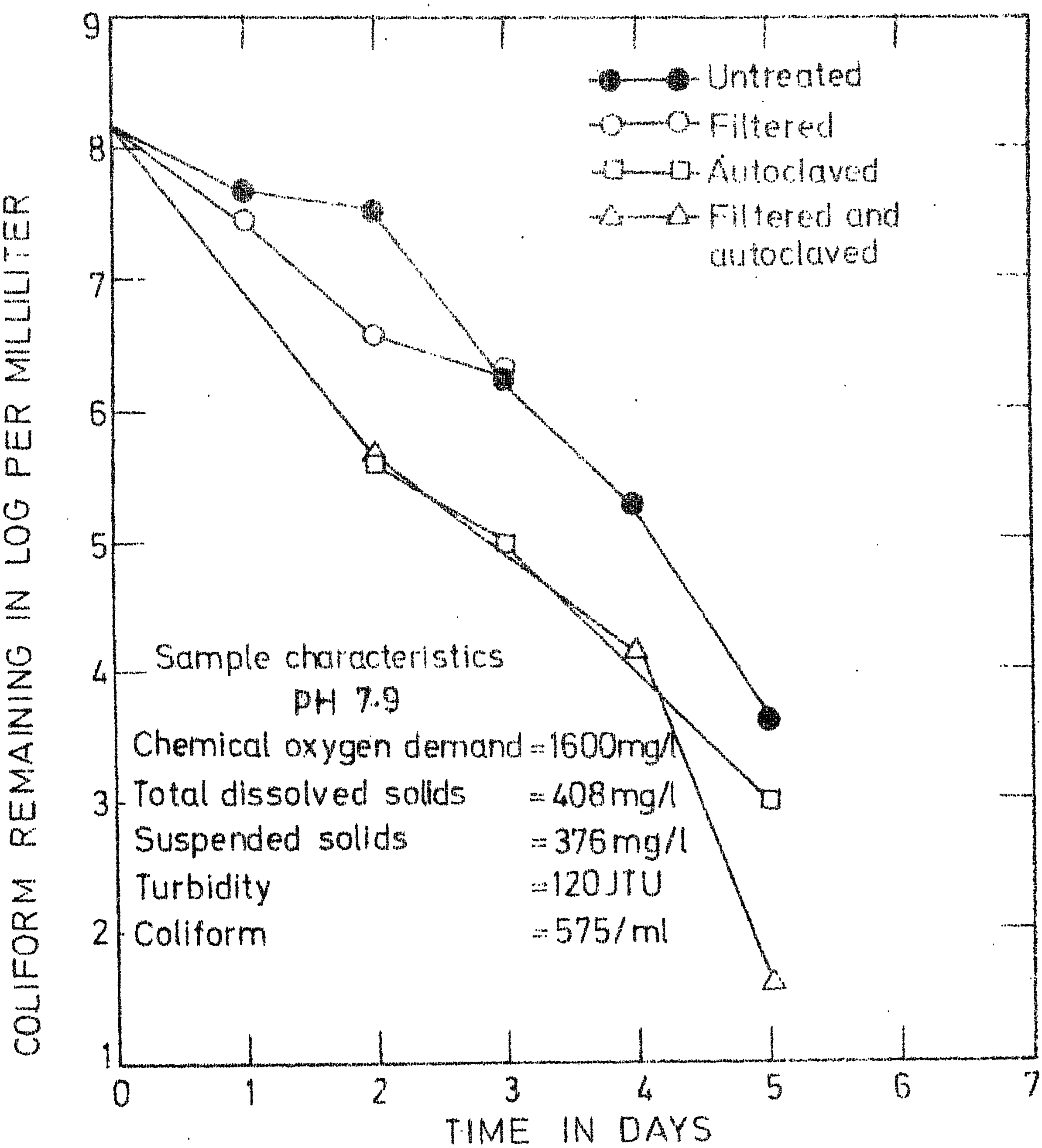

Fig. 4 Coliform survival in Railway Bridge water samp

of the removal of suspended solids prior to autoclaving.

The trend of coliform die-off observed in the Railway Bridge water sample subjected to various pre-treatment (Fig. 4) is rather difficult to explain. The untreated and the filtered samples showed almost the same trend whereas the autoclaved samples with or without prior filteration produced a somewhat more rapid coliform die-off. The reasons for these are not readily apparent. The suspended solids associated factor observed previously (Fig. 3) might have been masked due to the presence of higher concentration of organic matter in the Railway Bridge water sample. Krassilinikov (1938) while studying the bactericidal action of sea water also observed similar effects. The increased die-off observed in the autoclaved samples could be due to decomposition of some constituents of the sample during autoclaving which became toxic to the coliform organisms. This requires further investigation.

In order to investigate the suspended solids associated factor and its effect on coliform survival, an experiment was designed to study coliform survival in physiological saline with suspended solids, and suspended solids leachate obtained from the autoclaved Bhairon Ghat

water sample (Fig. 5): Increased die-off in presence of the suspended solids may be due to adsorption of the coliform organisms on the particulate matter as well as the effect of the suspended solids associated materials _per se_. The latter is further evidenced by noticeable increase in die-off in presence of the suspended solids leachate.

Subsequent to the above studies, two water samples were collected from Bhairon Ghat and Railway Bridge and analysed for total coliphage content using coliform bacteria isolated from Ganga water. Adams' soft agar overlay technique (Adams, 1959) was used for virus enumeration. The observed coliphage densities were 6 and 8 PFU/ml, and the ratios of coliphage to coliform bacteria were 1:30 and 1:70 for the Bhairon Ghat and Railway Bridge samples, respectively. Since these ratios are in the normal range observed with other rivers (Kenard and Valentine, 1974), the implication of phage in rapid coliform die-off in Ganga water as generally believed may be reasonably overruled.

It may be reasonably concluded from the preceding studies that rapid coliform die-off in the Ganga water is due to a factor (s) or principle (s) which is suspended solids associated,heat labile, and may be masked to some

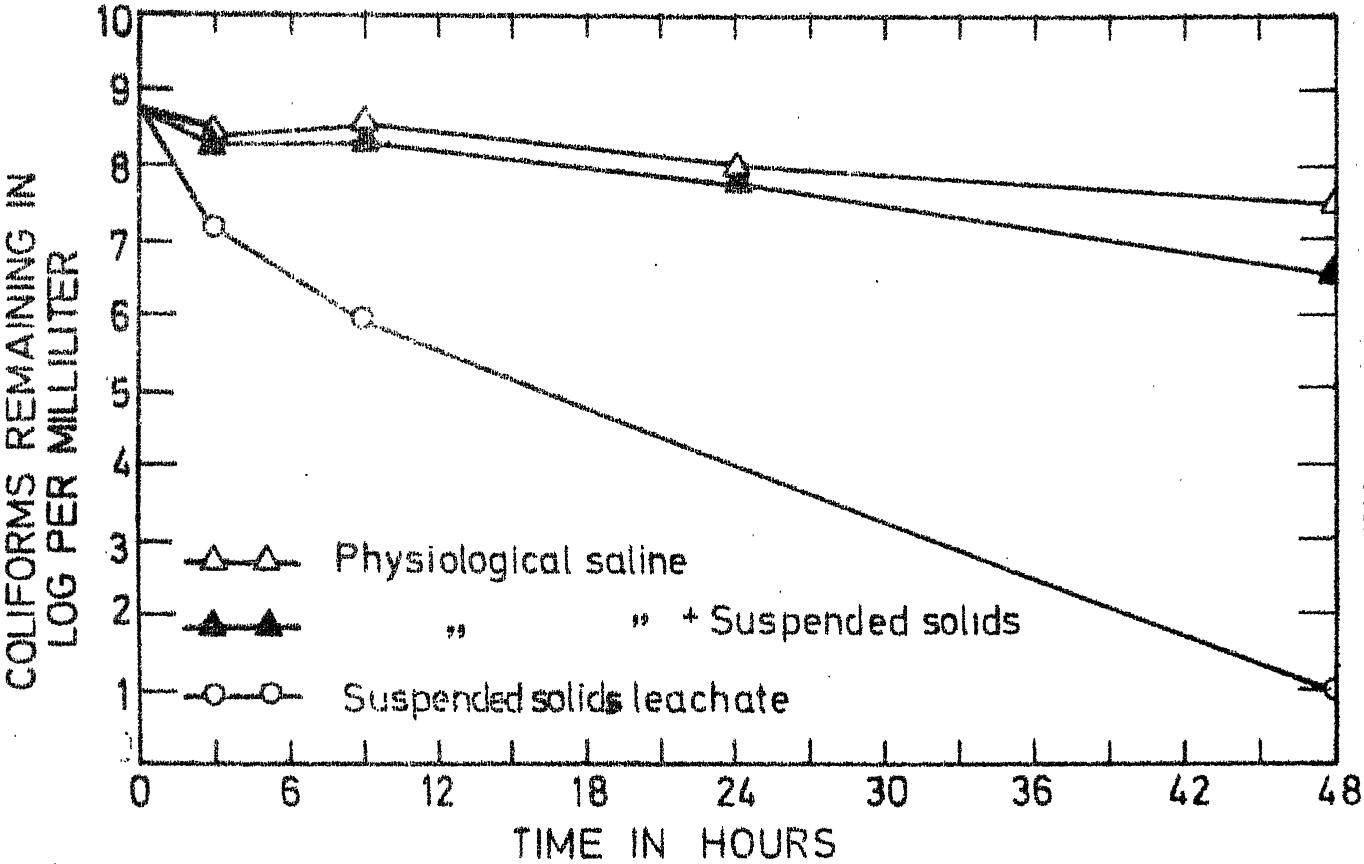

Fig.5 Effect of suspended solids and associated materia
on coliform survival in Bhairon Ghat water samp

extent when high concentrations of organic matter is present.

B. Application of Water Quality Indices

Figure 6 shows the variation of Walski-Parker and NSF (additive and multiplicative) water quality indices along the Ganga River near Kanpur using the data collected during the present study (May 23,1976) as well as that of Saxena et al. (1966) collected during the same month in 1966. The water quality indices without considering coliform density have been plotted in Fig. 7 to evaluate the sensitivity of the indices to this parameter. A look at the water quality data of 1966 and 1976 (Table 3) indicates that there has not been any significant change in the pollution load during the last decade except that coliform counts have gone down. The values for phosphate and turbidity are also somewhat lower in the 1976 survey. The slight improvement in water quality is well brought out by both the NSF models. The Walski-Parker model is unable to bring out the difference because of the higher weightage given to coliform density which is evident from Fig. 7 in which water quality indices have been plotted

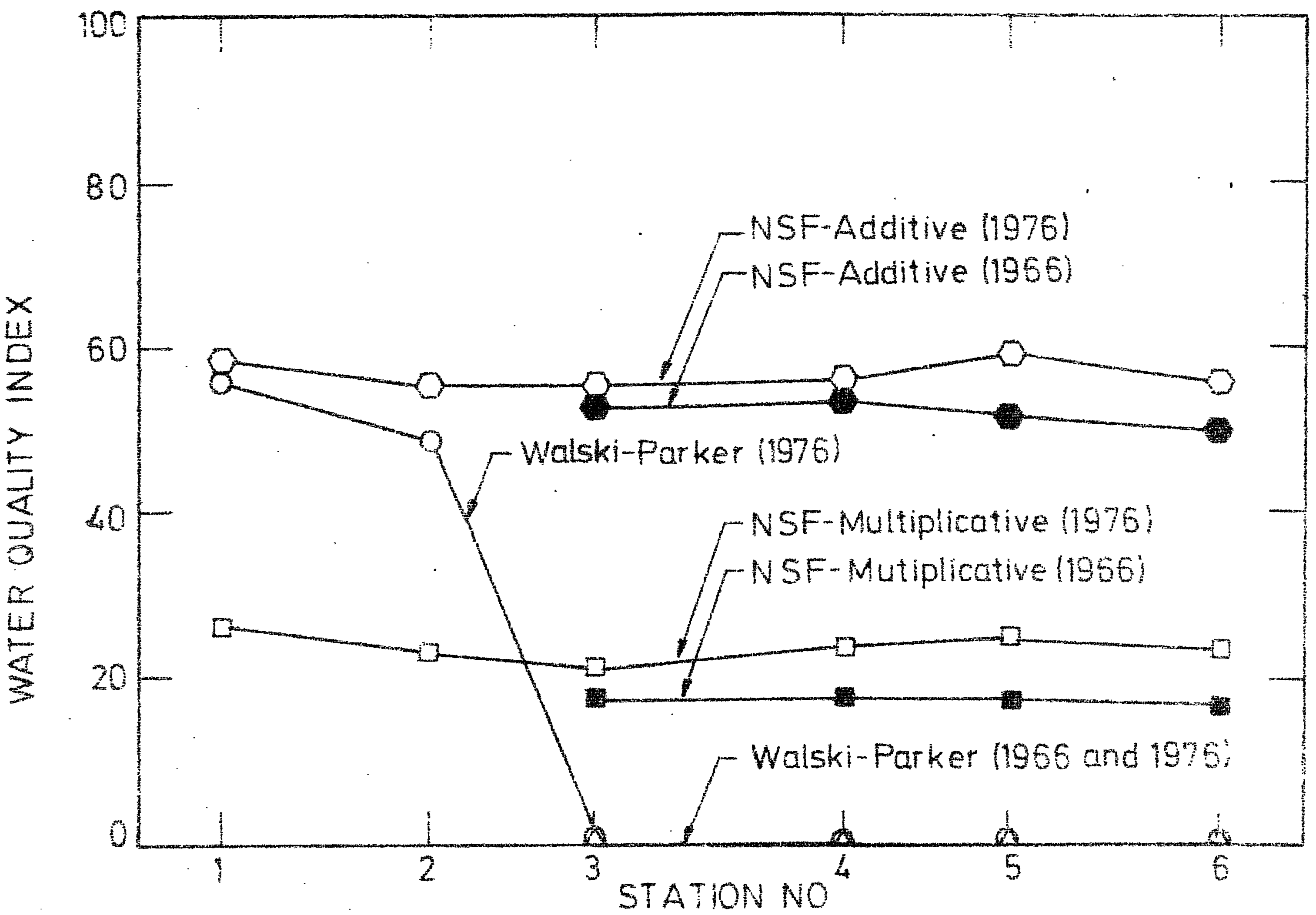

Fig.6 Variation of water quality indices along Ganga river

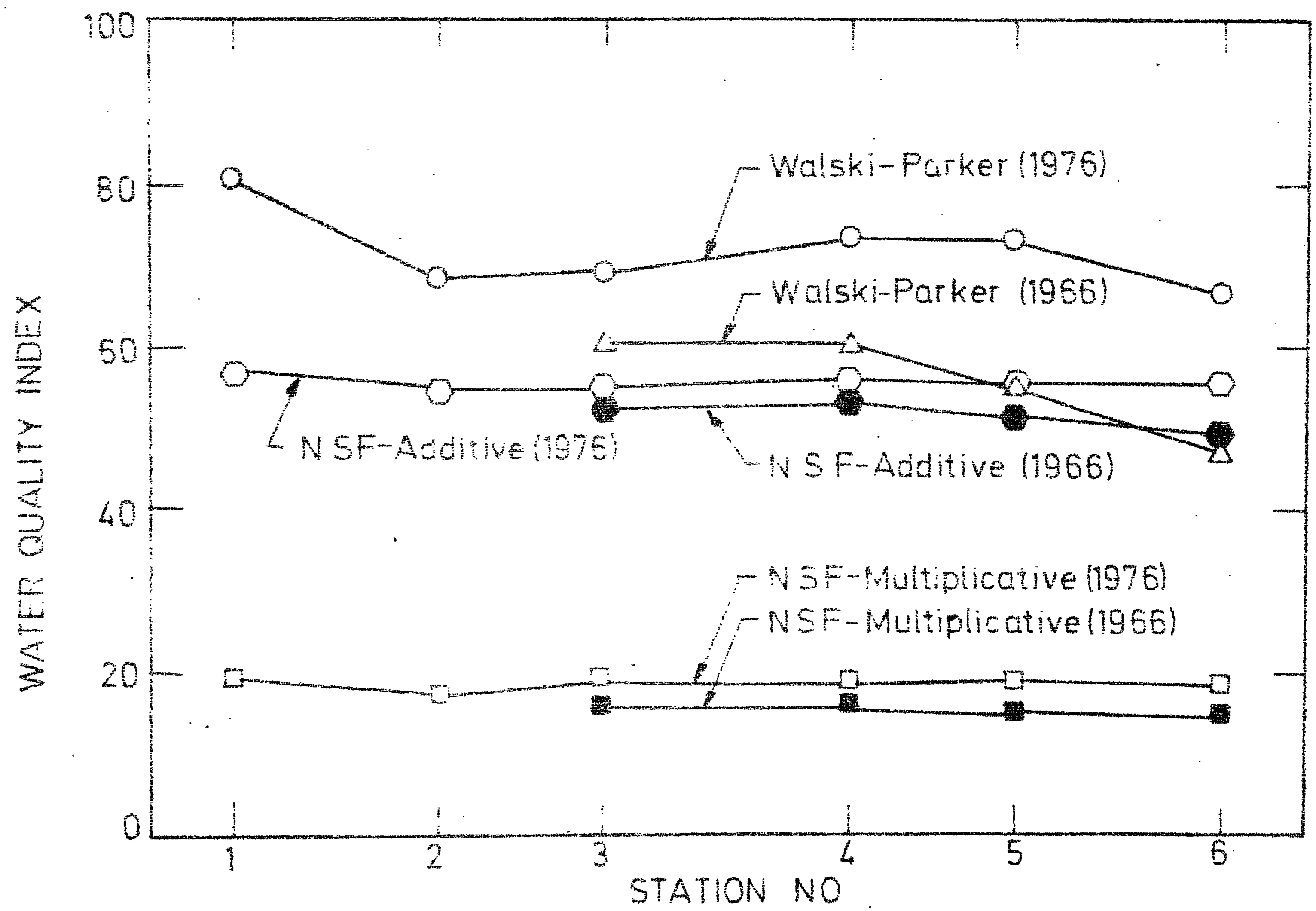

Fig.7 Variation of water quality indicesalong Ganga river near Kanpur without considering coliform density

Table 3. The Ganga River Water Quality Survey Data (May 23,1976)

Parameter	Station Number 1	2	3	4	5	6
pH	8.3	8.5	8.6	8.4 (8.3)	8.3 (8.2)	8.0 (8.3)
Dissolved oxygen in mg/l	7.1	7.1	6.7 (7.4)	7.3 (7.1)	6.6 (6.2)	6.3 (6.6)
Turbidity in JTU	54	45	43 (145)	60 (280)	40 (308)	35 (268)
Total phosphate in mg/l	0.1	0.075	0.15 (0.50)	0.10 (0.40)	0.125 (0.40)	0.127 (0.40)
Nitrate in mg/l	Traces	Traces	Traces (Traces)	Traces (Traces)	Traces (0.12)	Traces (0.05)
5 day 20°C biochemical oxygen demand in mg/l	1.9	4.8	3.5 (4.0)	3.8 (4.2)	3.0 (4.9)	4.5 (7.9)
Total coliform per 100 ml	8000	17500	170000 (610000)	35000 (856000)	190000 (2870000)	220000 (8666000)

Note: Data from a previous water quality survey (Saxena et al.,1966) conducted in May,1966 are shown in parentheses.

without considering coliform density. It may be concluded that the Walski-Parker model is more useful compared to the NSF models in predicting the water quality index for health related uses where coliform density is of major concern. On the otherhand, for non-health related activities, both the NSF models may be applicable.

VI. SUMMARY AND CONCLUSIONS

Coliform survival in the Ganga River near Kanpur was studied in the laboratory as well as in situ using dialysis sacs and compared with the available data for major rivers in the United States. The apparent rapid coliform die-off in Ganga water was further investigated in the laboratory using various sample pretreatment. It has been concluded that the factor (s) or principle (s) responsible for rapid coliform die-off in Ganga water is suspended solids associated, heat labile and may be masked to some extent when high concentration of organic matter is present.

A water quality survey of the Ganga River near Kanpur was also conducted during May, 1976 using six sampling stations. The data collected during this study and that available in the literature for the same month in 1966 were used to assess the applicability of the recently developed water quality indices, viz., NSF and Walski-Parker models. The Walski-Parker model has been found to be more useful in predicting the water quality index for health related uses whereas for non-health related activities, the two NSF models appeared suitable.

VII. SIGNIFICANCE OF THE STUDY AND SUGGESTIONS FOR FUTURE WORK

A. Significance of the Study

The present study has established a somewhat rapid die-off of coliform organisms in Ganga water and the factor(s) or principle(s) associated with such die-off. Considering that coliform index is still the accepted standard for microbiological quality of a water supply, this study coupled with the previous study of Khanna et al.(1971) is significant in terms of public health. The Ganga River is considered to be one of the most sacred rivers in India and a large number of people bathe in the Ganga River during various religious festivals and ceremonies. It would appear that the bathers are presumably not exposed to heavy bacteriological pollution inspite of a large number of municipal wastewater discharges along the river because of a rapid assimilative capacity of the river in terms of bacteriological pollution.

This study is also significant since the applicability of the recently developed water quality indices has been tested for the first time using water quality data of an Indian river. It has been shown that these indices are good

tools for a water quality engineer in predicting the quality of a natural body of water. However, it would appear that by varying the number of parameters to be included and their sensitivity or weightage, the water quality engineer may be able to make an index more applicable for a particular beneficial use.

B. Suggestions for Future Work

Based on the results of this study, it is felt that further work should be pursued in the following areas :

(i) Survival of coliform organisms in major Indian rivers should be studied using in situ dialysis technique and compared with that observed in the Ganga River.

(ii) A more detailed investigation should be undertaken to characterise the suspended solids associated as well as the heat labile factor(s) or principle (s) responsible for observed coliform die-off in Ganga water.

(iii) A further study is warranted to confirm and explain the coliform die-off pattern observed in the Railway Bridge water sample.

(iv) A more comprehensive river quality survey of the Ganga River should be conducted using a longer reach of the river during various seasons of the year to further establish the usefulness of the two water quality indices.

REFERENCES

Adams, M.H.(1959) Bacteriophage.Interscience Publ., New York, N.Y.

Berg, G., Scarpino, P.V., and Berman, D.(1966) Survival of Bacteria and Viruses in Natural Waters. Proceedings of Nat. Symp. on Quality Standards for Natural Water, The University of Michigan School of Public Health, U.S. Dept. of the Interior, Federal Water Pollution Control Administration, Cincinnati., Ohio.

Brown, R.M., McClelland, N.I., Deininger, R.A., and Tozer, R.G.(1970) A Water Quality Index-Do We Dare? Presented at the National Symposium on Data and Instrumentation for Water Quality Management, Madison, Wisconsin, and published in Water Sewage Wks., 117, 339.

Brown, R.M., McClelland, N.I., Deininger, R.A., and Landwehr, J.M. (1973) Validating the WQI. Presented at the National Meeting of the American Society of Civil Engineers, Washington, D.C.

Colmer, A.R., and Hinkle, M.E. (1947) Role of Microorganisms in in Acid Mine Drainage: A Preliminary Report. Science, 106, 253.

Dalkey, N.C. (1968) DELPHI. The Rand Corporation.

European Standards for Drinking Water (Second Edition).(1970) World Health Organization, Geneva.

Fair, G.M., Geyer, J.C., and CKun, D.A.(1968) Water and Waste-water Engineering, Volume 2. Water Purification and wastewater Treatment and Disposal. John Wiley and Sons, New York.

Frenkil, S.M. (1975) Water Quality Index for the Recreational Users of Urban Waterways. Presented at the Second Annual National Conference on Environmental Engineering Research Developments and Design, University of Florida, Gainesville, Florida.

Frost, W.H., and Streeter, H.W. (1924) Bacteriological Studies. A Study of the Pollution and Natural Purification of the Ohio River. Second Report on Surveys and Laboratory Studies. Treasury Department, U.S. Public Health Service. Public Health Bulletin , 143, 184.

Gallagher, T.P., and Spino, D.F. (1968) The Significance of Numbers of Coliform Bacteria as an Indicator of Enteric Pathogens. Water Research , 2,169.

Geldreich, E.E. (1966) Sanitary Significance of Fecal Coliforms in the Environment. Publication No. WP 20-3. Federal Water Pollution Control Administration, Cincinnati, Ohio.

Geldreich, E.E. (1970) Applying Bacteriological Parameters to Recreational Water Quality. Jr. Am. Water Wks. Assn., 62, 113.

Greenberg, S.M., and Arnold, E. (1956) Survival of Enteric Organisms in Sea Water. Public Health Report, 71, 77.

Hanes, N.B., Rohlich, G.A., and Sarles, W.B. (1966) Effect of Temperature on the Survival of Indicator Bacteria in Water. Jr. New England Water Wks. Assn., 80, 6.

Harkins, R.D. (1974) An Objective Water Quality Index. Jr. Water Poll. Control Fed., 46, 588.

Hendricks, C.W., and Morrison, S.M. (1967) Multiplication and Growth of Selected Enteric Bacteria in Clear Mountain Stream Water. Water Research, 1, 567.

Horton, R.K. (1965) An Index Number System for Rating Water Quality. Jr. Water Poll. Control Fed., 37,300.

Hoskins, J.K. (1926) Quantitative Studies of Bacteriological Pollution and Purification in the Ohio and Illinois Rivers. Trans. Am. Soc. Civil Engrs., 85, 1365.

Hoskins, J.K., and Butterfield, C.T. (1933) Some Observed Effects of Dilution on the Bacterial Changes in Polluted Water. Sewage Wks. Jr., 5,763.

Ingram, W.M., and Tarzwell, C.M. (1955) Selected Bibliography of Publications Relating to Undesirable Effect Upon Aquatic Life by Algicides, Insecticides and Weedicides. Sewage Ind. Wastes, 27, 244.

International Standards for Drinking Water (Third Edition). (1971) World Health Organization, Geneva.

Jordan, E.O. (1906) Some Observation upon the Bacterial Self Purification of Streams., Jr. Exp. Med.,5, 271.

Joyce, G., and Weiser, H.H. (1967) Survival of Enteroviruses and Bacteriophage in Farm Pond Waters. Jr. Am.Water Wks. Assn., 59, 491.

Kendall, M.G. (1963) A Course in Multivariate Statistics. Charles Griffin and Company, London.

Kenard, R.P., and Valentine, R.S. (1974) Rapid Determination of the Presence of Enteric Bacteria in Water. Appl. Microbiology, 27, 485.

Ketchum, B.H., Ayers, J.C., and Vaccaro, R.F. (1952) Processes Contributing to the Decrease of Coliform Bacteria in Tidal Estuary. Ecology,33, 247.

Khanna,P., Mishra, A.B.,and Saraswat, I.P. (1971) Preliminary Investigations on the Quality of Ganges Water. Jr. Inst. Engrs. (India), PHE Div., 50, 63.

Kittrel, F.W. (1969) A Practical Guide to Water Quality Studies of Streams. U.S. Dept. of Interior, Washington, D.C.

Kittrel, F.W., and Furfari, S.A. (1963) Observation of Coliform Bacteria in Stream. Jr. Water Poll. Control Fed., 35, 1361.

Klein, L. (1962) River Pollution 2: Causes and Effects. Butterworths, London.

Krassilinikov, N.A. (1938) The Bactericidal Action of Sea Water. Mikrobiologiia, 7,329.

McClelland, N.I. (1974) Project Report on Water Quality Index Application in KansasRiver Basin. Publication No. EPA-907/ 9-74-001, Environmental Protection Agency, Washington,D.C.

McGauhey, P.H. (1968) Engineering Management of Water Quality. McGraw-Hill, New York.

McKee, J.E., and Wolf, H.W. (1963) Water Quality Criteria. Publication 3-A. California State Water Quality Control Board, California.

O'Conor,M.F. (1971) The Application of Multi-Attribute Scaling Procedures to the Development of Indices of Water Quality. Ph.D. Dissertation, University of Michigan, Ann Arbor, Michigan.

Ormerod, K., and Kristensen,K.K. (1976) Manual on Analysis for Water Pollution Control (Revised Draft). WHO Regional Office for Europe, Copenhagen

Palmer, C.L. (1950) The Pollution Effects of Stormwater Overflows from Combined Sewers. Sewage and Ind. Wastes., 22, 154.

Purdy, W.C., and Butterfield, C.T. (1918) The Effect of Plankton Animals upon Bacterial Death Rates. Am. Jr. Public Health., 8, 499.

Rudolfs , W., Falk, L.L., and Ragotzkie, R.A. (1950) Literature Review on the Occurrence and Survival of Enteric, Pathogenic and Relative Organisms in Soil, Water, Sewage and Sludges and on Vegetation. Bacteria and Virus Diseases. Sewage Ind. Wastes., 22, 1261.

Saxena, K.L., Chakravarty, R.N., Khan, A.Q. and Chandra,H.(1966) Pollution of Ganges River. Env. Health., 8,3.

Standard Methods for the Examination of Water and Wastewater (Thirteenth Edition). (1971) American Public Health Association, New York.

Streeter, H.W. (1931) The Effect of Sewage Discharge on Streams. Sewage Wks. Jr., 3,713.

Public Health Service Drinking Water Standards (1962) United State Department of Health, Education and Welfare, Public Health Service, Washington, D.C.

van Donsel, D.J., and Geldreich, E.E. (1971) Relationships of Salmonella to Fecal Coliforms in Bottom Sediments. Water Research, 5, 1079.

Walski, T. M., and Parker, F.L. (1974) Consumer Water Quality Index. Jr. Env. Eng. Div., Proc. Am. Soc. Civil Engrs., 100, 10601.

Water Quality Criteria (1972) A Report of the Committee on Water Quality Criteria. Environmental Studies Board, National Academy of Sciences and National Academy of Engineering, Washington, D.C.

APPENDIX

Table 1A. Sensitivity Functions for Walski-Parker Water Quality Index

1. pH: $f(pH) = [25-(pH-7)^2]/25$, $2 \leq pH \leq 12$;
   and $f(pH) = 0$, $pH < 2$, $pH > 12$

2. Dissolved Oxygen: $f(DO) = \exp[0.3(DO-8)]$, $DO \leq 8$;
   and $f(DO) = 1$, $DO > 8$

3. Turbidity: $f(Tur) = \exp(-0{,}001\ Tur)$

4. Phosphate: $f(p) = \exp(-2.5p)$

5. Nitrate: $f(N) = \exp(-0.16N)$

6. Coliform: $f(C) = \exp(-0.0002\ C)$

7. Biochemical Oxygen Demand: $f(BOD_5) = \exp(-0.346\ BOD_5)$

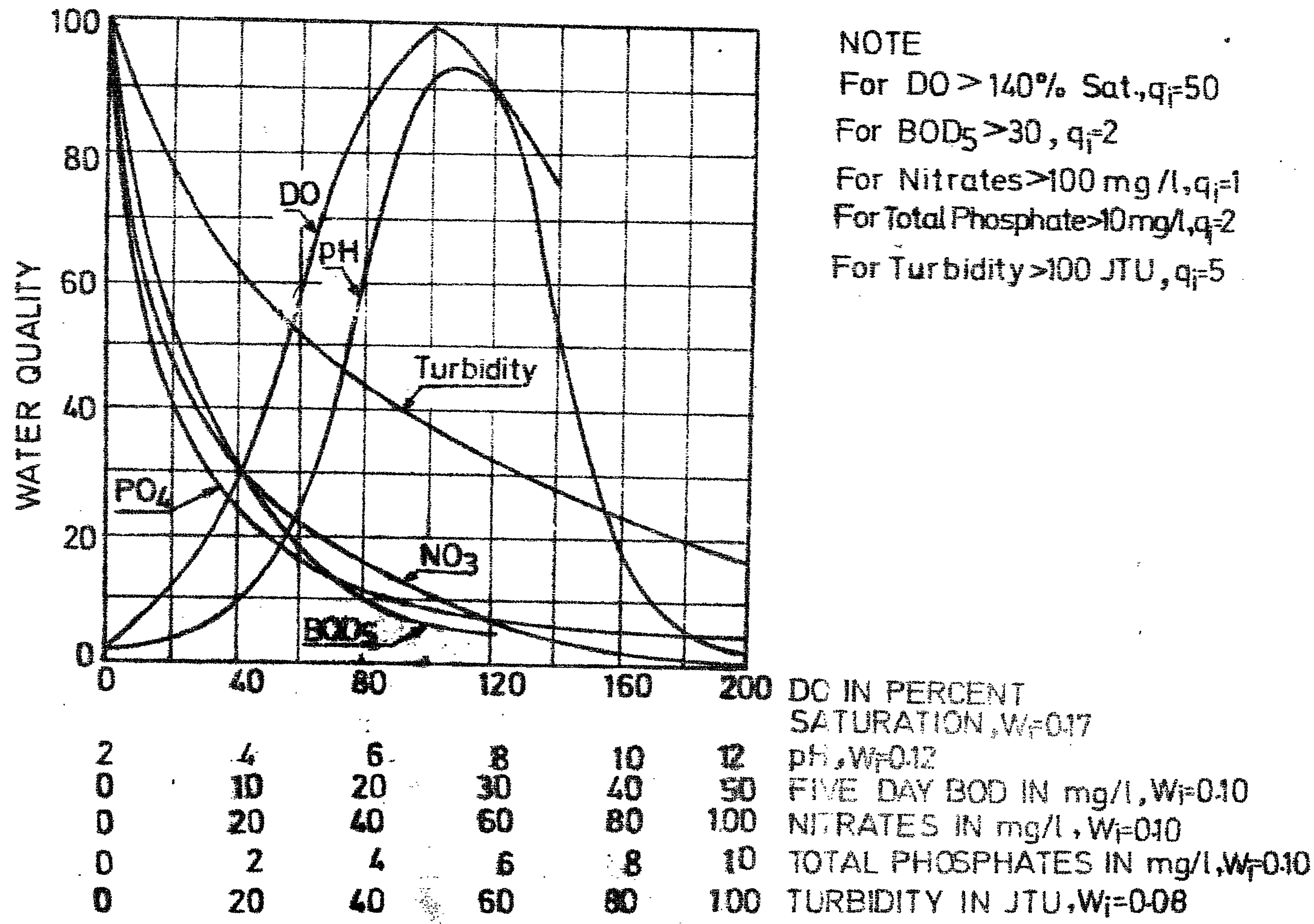

Fig.1A NSF Quality curves (McClelland,1974)

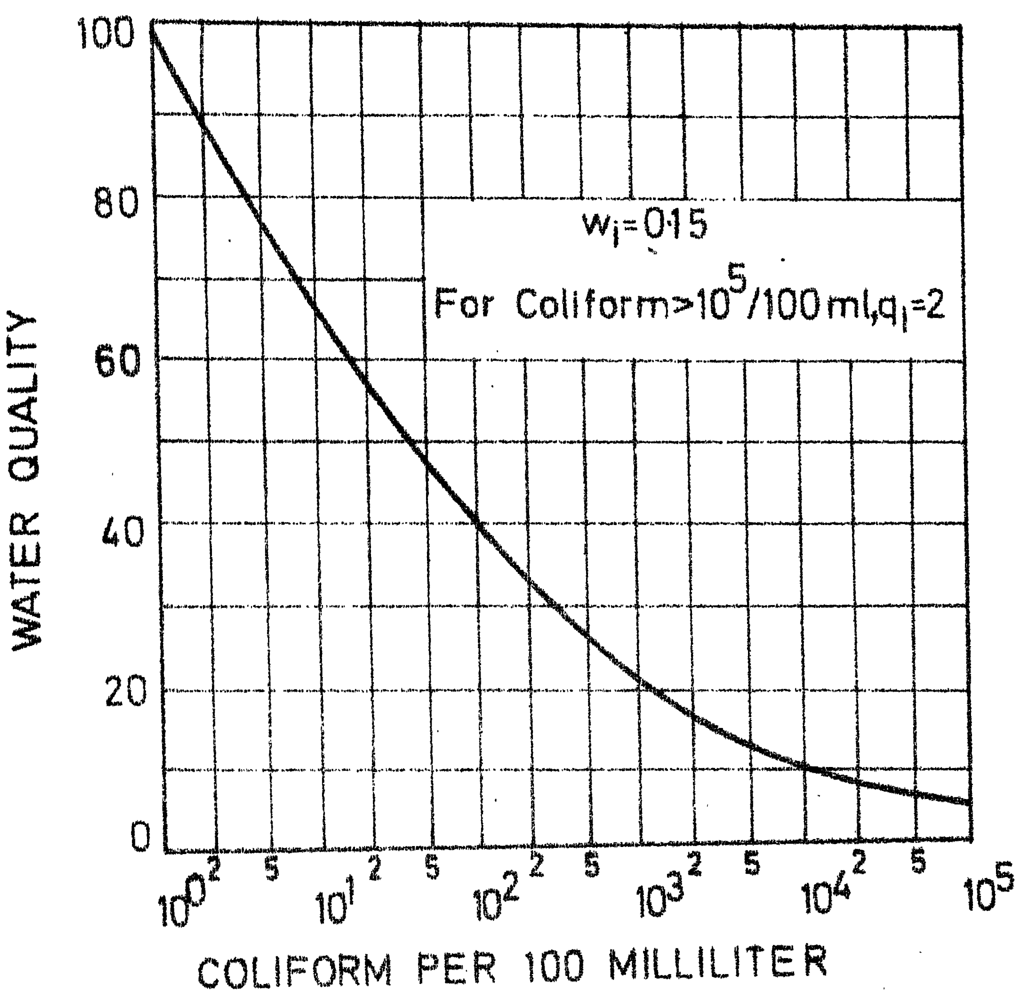

Fig. 2A NSF quality curve for coliform (McClelland, 1974)